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# Impact of Antenna Separation on the Link Correlation of MIMO HetNet LTE-Advanced Networks

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**Abstract-** Since the angular spread is related to the propagation environment condition, MIMO channel capacity can be improved by increasing the antenna spacing. This paper evaluates the performance of link correlation for 2x2 MIMO deployments using horizontal and vertical UE and BS array configurations with various antenna separations at the UE and BS. The investigation makes use of measured 3D radiation patterns for the BS and UE antennas. This data is combined with state-of-the-art 3D ray-tracing predictions for a large number of macro and pico-cells locations. Results revealed that in order to achieve a correlation always in the range 0.25 to 0.75, the minimum required antenna spacing was around  $0.5\lambda$  to  $2\lambda$  for the UE,  $2\lambda$  for the Pico-eNB and  $10\lambda$  for the Macro-eNB. MIMO performance (in terms of capacity) was seen to increase in pico-cells as a result of the higher angular spreads at the base station.

**Index Terms**— *HetNets, Cellular networks, Pico-cell, OFDMA.*

## I. INTRODUCTION

From a link performance perspective, LTE already achieves data rates very close to the Shannon limit. Increasing the number of cells has always been the main means of adding capacity. Since the data traffic demands in cellular networks are growing rapidly, significant improvements are now required in spectral efficiency. One of the key contributors to global mobile traffic growth is the transitioning to smarter mobile devices. According to the mobile data traffic statistics reported in [1], global mobile data traffic increased at a compound annual growth rate (CAGR) of 81% in 2013 and achieved 1.5 exabytes per month by the end of 2018. Mobile data traffic for smartphones and tablets is predicted to double each year from 2013 to 2018 [1] as demonstrated in Fig. 1. Finding in the same statistics indicate that mobile devices and networks will rise at a CAGR of 8 % to 10.2 billion by 2018. 1000 times more capacity is predicted over 10 years period. The performance of MIMO is critically dependent on the availability of independent spatial channels. It is well-known that channel correlation degrades the performance of a MIMO system. Spatial correlation is dependent on the 3D multipath structure of the radio channel. Multipath signals

depart from the base station with a given Angle of Departure (AoD). At the mobile terminal, the multipath signals arrive via a unique set of Angle of Arrivals (AoA). Spatial correlation in the horizontal plane is related to the azimuth angle spread, while spatial correlation in the vertical plane is related to the elevation angle spread. The ray-tracing engine identifies all possible ray paths between the base station and the mobile receiver and was used previously to generate the models reported in [2–3].

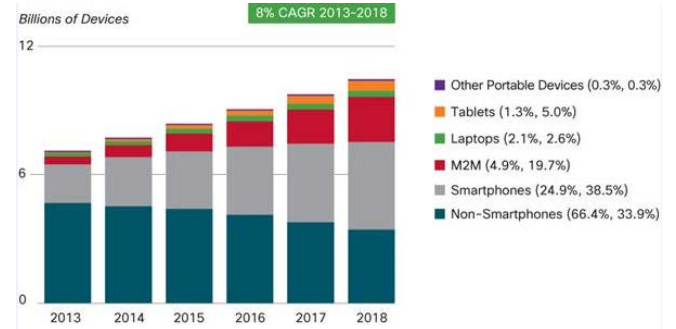


Figure 1: Global Mobile Devices and Connections Growth [1].

Recent work has proposed 3D extensions to the 3GPP/ITU channel model [2–4]. The 3D outdoor ray-tracer [5] channel between each BS and UE is preferred over the standardised 3GPP/ITU/WINNER channel models since they use simplified angle spread distributions, restrict propagation to the azimuth plane (elevation is ignored), use highly simplified polarization models, do not have mechanisms to model specific antenna patterns and do not model the pico-cells required for HetNets analysis. This paper exploits the link correlation of 3D channel models in [2–4] in order to investigate the viability of the pico-cells and macro-cells in a HetNet scenario with various user equipment (UE) and base station (BS) array configurations and antenna spacing. The initial deployments of LTE consist of macro base stations and UEs that caters for high mobility users. However, heterogeneous networks, also known as HetNets, are an emerging technique for increasing LTE-A network capacity by complementing the macro layer with a number of low-power pico base stations [6]. This method has been

stated to increase peak data rates in addition to entire network capacity. This paper expands on [7] by considering a HetNet deployment for 2x2 MIMO links with different base station array configurations for a very large number of links (4,076 macro base station (BS)-User Equipment (UE) links and 7,283 pico BS- UE links). The terms handset or User Equipment (UE), Base Station (BS) or Macro eNode B (Macro-eNB) and Pico- base station or Pico eNode B (Pico-eNB) are used interchangeably in this paper. This paper makes the following key contributions:

1. An analysis of the performance of link correlation for 2x2 MIMO deployments using horizontal and vertical UE and BS array configurations.
2. An analysis of element spacing's in pico and macro-cells.

Section II presents the background of the MIMO channel model with a highlighting on spatial link correlation. Section III describes the simulated data collection method used in this paper. Section IV explains the system design and parameters used in this study. Performance of link correlation coefficients in Rayleigh, Rician fading channels and medium correlation coefficients with different antenna spacing at the UE and eNB are presented in Section. Finally, conclusions are drawn in Section V

## II. SIMULATED DATA COLLECTION

The propagation data for this study was acquired at 2.6GHz in urban areas of central Bristol, (17.6 km<sup>2</sup>). The spatial and temporal characteristics of the radio channel were combined with appropriately oriented complex polarimetric 3D antenna patterns. In this paper, the work is performed based on 23 macro base stations and 200 pico base stations. For each BS-UE link, a set of 1000 uncorrelated fast fading channel snap-shots were generated.

The radiation patterns for a macro-cell BS antenna, a pico-cell BS antenna and a UE antenna were measured in our anechoic chamber. All antenna radiation patterns are 3D and include full phase and polarisation information as summarized in [3]. The gain is equal to the directivity as all of our antennas are assumed to be 100% efficient. A detailed statistical analysis of the propagation parameters can be found in [3]. The method described in [8] was used to compute a statistically valid set of wideband channel matrices suitable for Orthogonal Frequency Division Multiplexing (OFDM) modelling. The propagation features and performance of the pico-cells and macro-cells are presented in Fig.1 as CDFs of the K-factor, the RMS delay spread, the RMS AoD and the RMS AoA in the azimuth and elevation planes. The results in Figs.2(a) and (b) show that the RMS delay spreads are statistically higher in the macro-cells (since they illuminate a larger volume of the city), as are the values of K-factor (higher mounted macro-cells are more likely to generate a dominant multipath component).

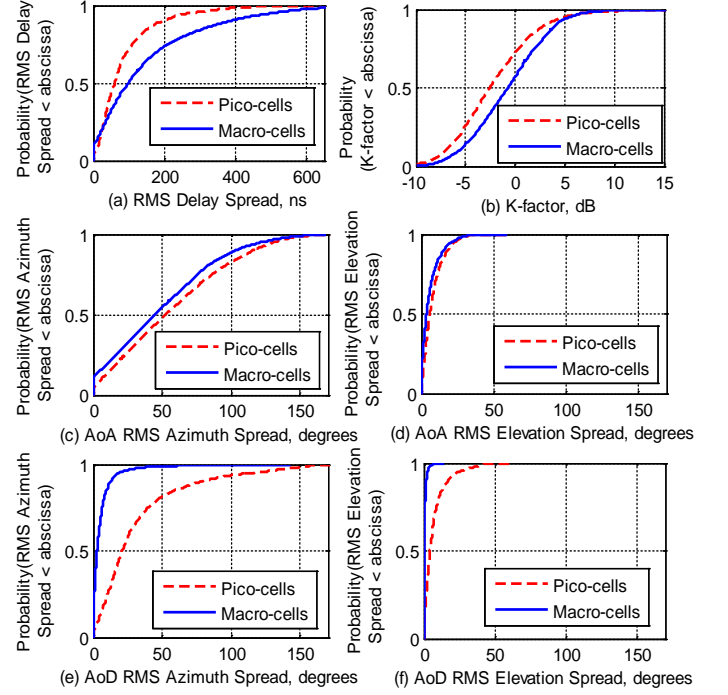


Figure 2: CDFs of macro-cell and pico-cell propagation characteristics.

## III. SYSTEM DESIGN AND PARAMETERS

In this paper, the LTE-A downlink for 2x2 MIMO was designed and implemented in MATLAB using the baseband link-level simulator. Both horizontal and vertical array configurations are considered for various antenna spacings at the UE and BS as summarised in Table 1. The UE, macro-cell and pico-cell BSs were modelled to employ two horizontally or two vertically spaced antennas. All the physical layer parameters, unless explicitly stated, are stated in [9]. The PER for each of the MIMO OFDMA PHY layer transmission modes is simulated as a function of SNR using MIMO channel data extracted from the 3D ray-tracing model. The MCS considered in the simulation for 2x2 MIMO are given as in [9]. The achievable throughputs at the PHY layer can be calculated from the error free data rate and the residual packet error rate. An approximation for throughput is given by  $Throughput = (1 - PER) \times R_b$ , where the  $R_b$  represents the peak error-free transmission data rate and PER is the residual PER for a specific MCS mode.

Table 1: UE antenna spacing

| UE antenna spacing | Handset      |              | Tablet              |                     |
|--------------------|--------------|--------------|---------------------|---------------------|
|                    | Potrait      | Landscape    | Potrait             | Landscape           |
| Horizontal         | $0.5\lambda$ | $\lambda$    | $\lambda$           | $\lambda, 2\lambda$ |
| Vertical           | $\lambda$    | $0.5\lambda$ | $\lambda, 2\lambda$ | $\lambda$           |

In this investigation, the link correlation coefficients for 2x2 MIMO are defined by 6 coefficients which are  $\alpha$  and  $\zeta$  for the UE,  $\alpha$  and  $\eta$  for the BS, and  $\gamma$  and  $\sigma$  for the UE-BS as stated in Table 2. For the case of 2x2 MIMO the channel

matrix is given as  $\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$ , and the complete MIMO channel link correlation matrix,  $\rho_{\mathbf{H}}$  can be described as

$$\rho_{\mathbf{H}} = \rho_{eNB} \otimes \rho_{UE} = \begin{bmatrix} 1 & \alpha & \beta & \gamma \\ \alpha^* & 1 & \sigma & \eta \\ \beta^* & \sigma^* & 1 & \varsigma \\ \gamma^* & \eta^* & \varsigma^* & 1 \end{bmatrix}, [2] \text{ where}$$

$$\alpha = \{\mathbf{H}(1,1)\mathbf{H}^*(1,2)\}, \beta = \{\mathbf{H}(1,1)\mathbf{H}^*(2,1)\}, \gamma = \{\mathbf{H}(1,1)\mathbf{H}^*(2,2)\}, \\ \sigma = \{\mathbf{H}(1,2)\mathbf{H}^*(2,1)\}, \eta = \{\mathbf{H}(1,2)\mathbf{H}^*(2,2)\}, \varsigma = \{\mathbf{H}(2,1)\mathbf{H}^*(2,2)\}$$

Table 2: Link Correlation Coefficients.

|                     |                 |                     |
|---------------------|-----------------|---------------------|
|                     |                 |                     |
| (a) UE- $\alpha$    | (b) BS- $\beta$ | (c) UE-BS- $\gamma$ |
|                     |                 |                     |
| (d) UE-BS- $\sigma$ | (e) BS- $\eta$  | (f) UE- $\varsigma$ |

#### IV. LINK CORRELATION PERFORMANCE ANALYSIS

Fig. 3 shows the link correlation coefficients for pico-cells and macro-cells in Rayleigh and Rician fading channels with the horizontal and vertical BS antenna array configuration. The Rayleigh channel is determined by the  $K$ -factor  $< 0$  dB and the Rician channel by  $K$ -factor  $> 0$  dB. The correlation of the links as the eNB uses either a horizontal or vertical array was found to be much higher in Rician fading than in Rayleigh fading conditions. In Rician fading, the link correlation is far worse due to the higher dominant component in both pico-cells and macro-cells.

In Rayleigh fading, the link correlation as a function of the UE and BS antenna spacing was determined for pico-cells and macro-cells, where both the UE and BS use a horizontal array, as shown in Fig. 4. From this figure, the link correlation decreases as the UE antenna spacing increases, as expected. In general, the link correlation at the UE and BS is higher in macro-cells compared to pico-cells. It can be seen from Fig. 4 (a) that the link correlation for an antenna spacing of  $2\lambda$  was 0.59 for pico-cells and 0.64 for macro-cells. Meanwhile, at the BS (refer to Fig. 5(b)), the link correlation for a  $10\lambda$  spacing was 0.53 for pico-cells and 0.72 for macro-cells. In order to analyse the spatial correlation in terms of antenna array configuration and antenna spacing, the link correlation coefficients in this investigation are defined by 2 classes; 0.25 or less denoting high MIMO performance and 0.75 more denoting low MIMO performance, where  $P(X \geq 0.75) = [1 - P(X \leq 0.75)]$ .

Fig. 5 shows the probability of the link correlation for pico-cells and macro-cells respectively. Significantly, there are more selected MIMO connections for the pico-cellular scenarios compared to the macro-cellular scenarios. It can be seen that high throughput MIMO connections are more likely to be obtained when the BS uses a horizontal array.

The impact of the antenna spacing on the percentage of links in pico-cells and macro-cells with a MIMO connection is further investigated where  $0.25 \leq X \leq 0.75$  denotes medium MIMO performance shown in Fig. 6. Antenna spacings of  $\lambda$ ,  $2\lambda$  and  $3\lambda$  are explored for Pico-eNBs and  $3\lambda, 5\lambda$  and  $10\lambda$  for Macro-eNBs. The UE antenna spacings are  $0.5\lambda, \lambda$  and  $2\lambda$ . It is interesting to note that the correlation for the UE-BS link obtain higher MIMO performance compared to the UE and BS. In both scenarios increasing the eNB antenna spacing has less influence in the pico-cells; however this has a significant impact in the macro-cells, especially for the vertical antenna array case. Based on the percentage link correlation values in the range 0.25 to 0.75, the minimum required antenna spacing is around  $0.5\lambda - 2\lambda$  for the UE,  $2\lambda$  for the Pico-eNB and  $10\lambda$  for the Macro-eNB.

Fig. 7 shows the capacity performance of the MIMO enabled pico-cells and macro-cells for measured antenna patterns at an SNR of 15 dB. System capacity is seen to improve in the pico-cells, where larger values of angular spread are observed. It can be seen that pico-cells exhibit a higher capacity compared to macro-cells as the angular spread increases. Horizontal eNB antenna configurations exhibits a higher capacity compared to vertical configurations in both pico-cells and macro-cells. Vertical eNB configurations are well suited to pico-cells since they provide similar capacity values to horizontal configurations. However, in macro-cells the vertical eNB antenna configuration performance for the points under study offers approximately a 3% loss over the horizontal configuration. This is due to the fact that the spatial correlation values in macro-cells with horizontal configurations are much lower than for vertical configurations. This implies that the decrease in capacity in the vertical configuration case is due to higher spatial correlation. Pico-cells can be expected to play a pivotal role in HetNets since even when the SNR values are normalized; they still delivery higher values of capacity. By exploiting vertical array, it is possible to generate more compact array for BS with 4 or 16 array elements.

#### V. CONCLUSIONS

This paper has presented a study of the effect of antenna separation on the link correlation of 2x2 MIMO HetNet LTE-Advanced Networks. The macro and pico-cells propagation characteristics between the user terminals and base stations have been described. The correlation of the links as the base station uses either a horizontal or vertical

array was found to be much higher in Rician fading than in Rayleigh fading conditions. Results shown that in order to achieve a correlation always in the range 0.25 to 0.75, the minimum required antenna spacing was around  $0.5\lambda$  to  $2\lambda$  for the UE,  $2\lambda$  for the Pico-eNB and  $10\lambda$  for the Macro-eNB. The antenna spacing at the macro BS antenna array can increase to  $20\lambda$  as the size of the macro BS is huge compared to pico BS. MIMO performance (in terms of capacity) was seen to increase in pico-cells as a result of the higher angular spreads at the base station. The results demonstrated that pico-cells attained better link decorrelation values (relative to macro-cells) and hence better exploit the benefits of MIMO.

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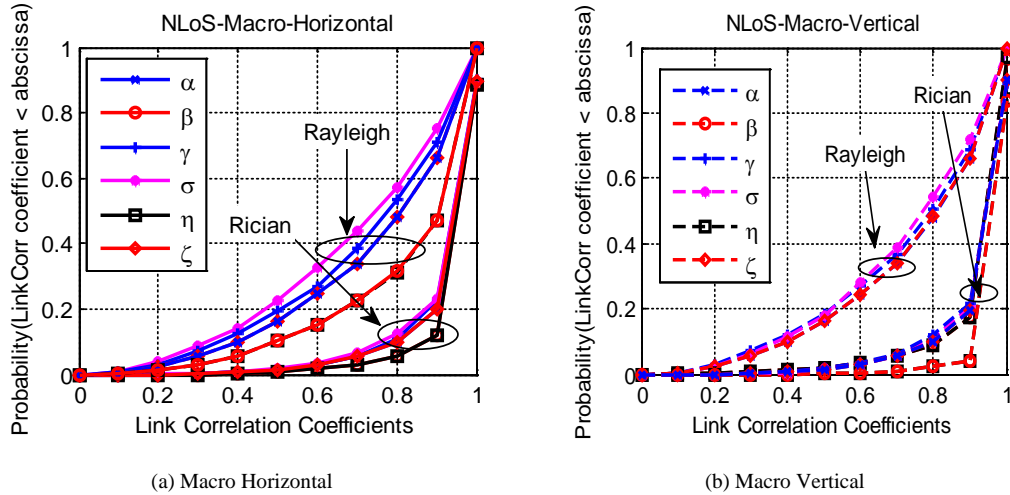


Figure 3: The CDF of link correlation coefficients for Rayleigh and Rician fading channels.

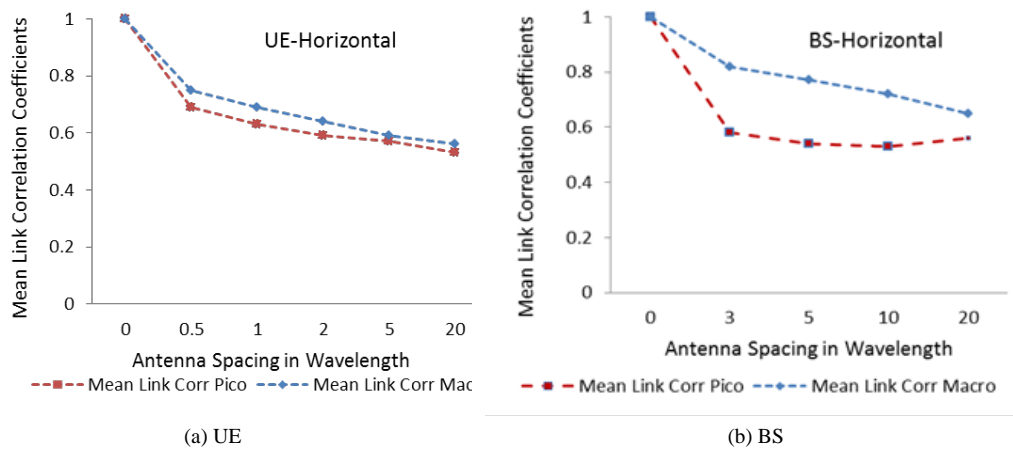
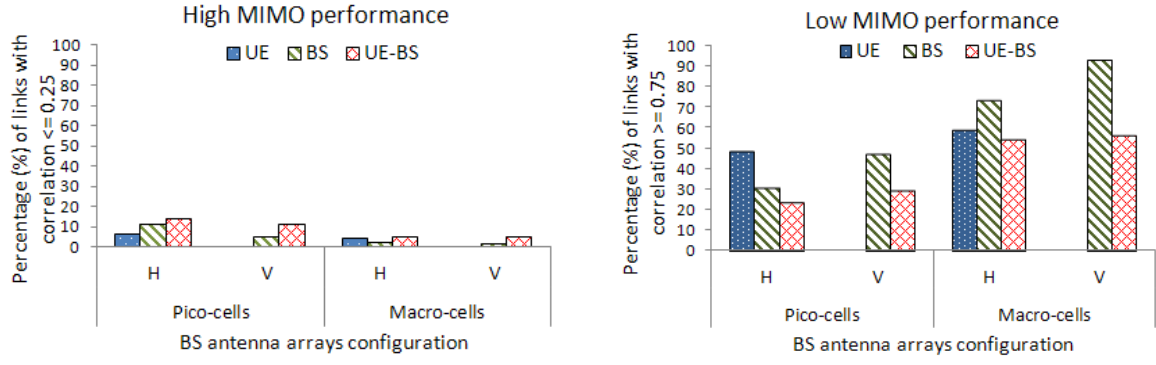


Figure 4: The mean link correlation coefficient in pico-cells and macro-cells versus antenna spacing.

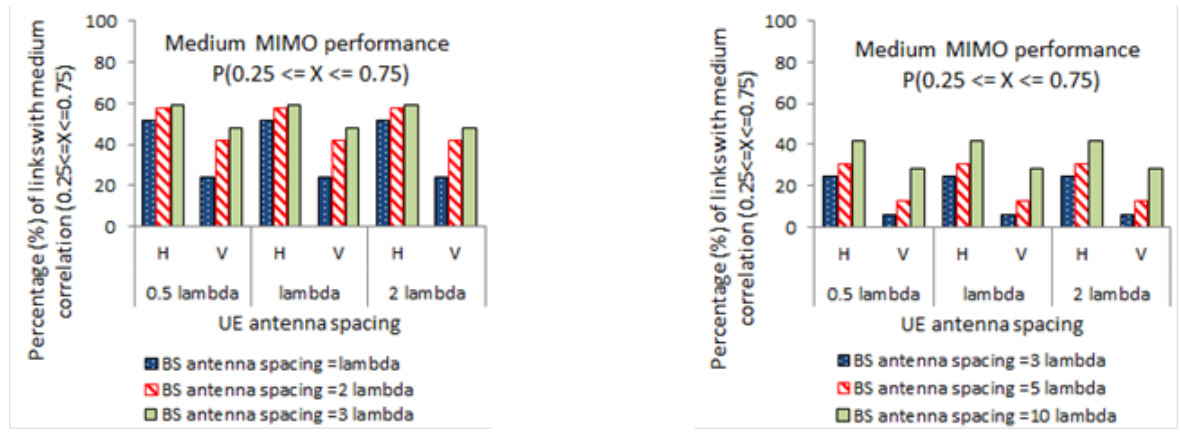




(a) High MIMO performance

(b) Low MIMO performance

Figure 5: Percentage (%) of links with correlation where the BS antenna spacing is  $3\lambda$  and the UE antenna spacing is  $0.5\lambda$ . The antenna array configuration is horizontal at the UE; and horizontal or vertical at the BS.



(a) BS (Pico)

(b) BS (Macro)

Figure 6: Percentage (%) of links with medium correlation where the Pico-eNB (left) antenna spacing is  $\lambda$  and the Macro-eNB (right) antenna spacing is  $10\lambda$ . The UE antenna array configuration is horizontal and the BS uses horizontal or vertical spacings in both the pico-cell (left) and macro-cell (right) scenarios.

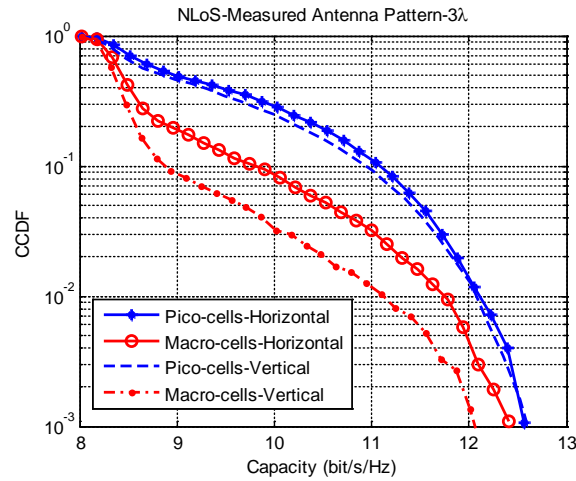


Figure 7: The CCDF of Ergodic capacity at SNR 15 dB for horizontal or vertical eNB antenna configurations.